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A PIGMENT COLOR SYSTEM AND NOTATION¹

By A. H. MUNSELL

It may be assumed that this audience is acquainted with previous schemes by Lambert, Rünge, Chevreul, Benson and others:—also experimental results obtained by Maxwell, Helmholtz, Koenig, Rood, Abney, Wundt, Hering and Nagel.²

The germ of the present system was a twirling color model made in 1879 when as a student of painting I read Professor Rood's "Modern Chromatics." Experience with many students since then has led to its elaboration in a hope to clarify some of the vague and even false notions frequently entertained.

It is an experimental system built up with the aid of a new photometer, Maxwell discs and the trained capacity of the painter,—using a consensus of many individual decisions to gain the mean of color discrimination. A value scale (painter term for luminosity) was first made by measured dilutions of India ink, furnishing sixteen supposedly equal intervals from black to white. A *middle* value in this scale was next determined by the average choice of artists, dyers, salesmen and students to whom it was submitted, and from this middle point the gradations to white and black were equalized by Maxwell discs. But the eye detected a lack of continuity in the two halves of the scale, which was then rejected in favor of a logarithmic progression.

Thus, unsuspected, the law of sensation dictated the scale of values, instead of the intensity scale common to photometers, and the present daylight instrument was devised to preserve the conditions of studio practice, after having discarded the usual dark room installations with artificial light. An Aubert diaphragm was used to approximate the law of sensation:—but later, in constructing scales of *chroma*, an exception to the law was encountered, which has been noted elsewhere.³

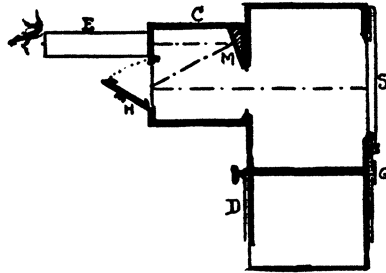
¹ Read before the American Psychological Association, Washington, Dec. 27, 1911.

² Lambert, 1772. Rünge, 1810. Chevreul, 1890. Benson, Clerk-Maxwell, 1860. Helmholtz, 1867. Rood, 1879. Koenig, 1894. Abney, 1896. Wundt, 1880. Hering, 1878. Nagel, 1908.

³ *Psychol. Bulletin*, VI, 1909, 238 f.

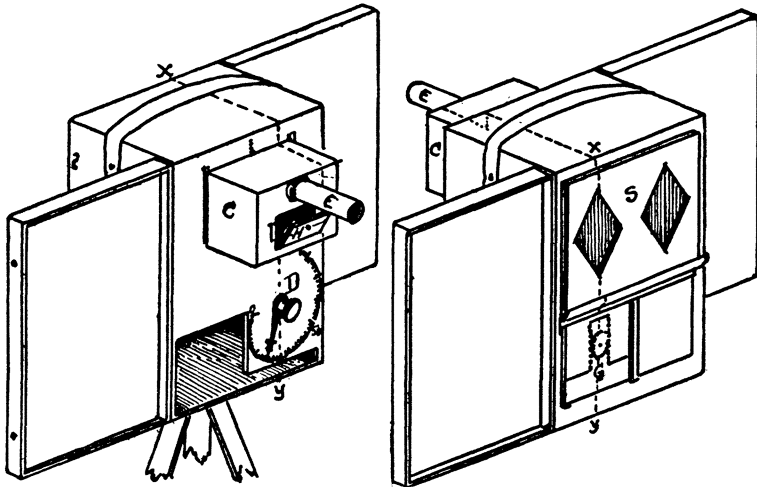
Method of classification

(Summary by Dr. L. J. Henderson of the solid described in "A Color Notation.")



“ The principle of this classification of colors depends upon the recognition of three dimensions:—*value*, *hue* and *chroma*.

“These three dimensions are arranged as follows. A central vertical axis represents changes in value from white at



the top to black at the bottom,—the progression being a logarithmic one to correspond with the Weber-Fechner law.⁴ The value of every point on this axis determines the level of every possible color of equal value.

* HELMHOLTZ. Handbuch der Physiologischen Optik, zweite Auflage. Hamburg, 1896, 384-480.

"Radial planes leading from this axis correspond each to a particular hue. Opposite radial planes correspond invariably to complementary colors: any three planes separated by 120° form a complementary trio, etc. Thus the angular position of any hue is determined, and the hues are balanced.

"Chroma, or intensity of hue, is measured by the perpendicular distance from any point to the vertical axis, and the progression of chroma is an arithmetical one, constituting the exception to the law already noted.

"Thus is constructed a solid. In this solid every horizontal plane corresponds to one and only one value. Every vertical plane extending radially from the central vertical axis contains colors of but one hue. Finally, the surface of every vertical cylinder having the vertical axis as its principal axis contains colors of equal chroma.

"In this solid every point corresponds to one and only one color, of definite value, hue and chroma, and when these three dimensions of a color have been measured its position in the solid is at once obvious."

What material form shall be given to this theoretic color solid? Spectral color would be the first suggestion because of its purity and the perfection of its instruments. But were it possible to embody the theory in spectral form, there would still remain its translation into pigments for the daily applications in education and industry.

There are serious pigment difficulties which must be met, such as fading and chemical reaction; and long technical experience is needed in handling pigments, so that inequalities of texture left by the brush, and uneven transparency affecting the relation of body and surface light⁵ may not falsify results. The medium employed,—whether wax, oil or water, still further complicates the problem. Yet despite these limitations, some tolerably permanent visible form must be made and therefore pigments seem indispensable.

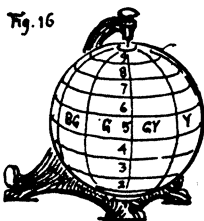
To meet these difficulties, expert knowledge is needed to devise tests and safeguards which will give the nearest approximation to uniformity. The scales must be made with the fewest possible pigments, which long exposure will not fade, and after careful scrutiny of their chemical composition. To avoid irregular behavior in the reflection and absorption of light, those selected for this system of charts have been ground in media which gives a matt surface when applied to a special ground.

⁵ WILHELM OSTWALD. *Letters to a Painter*. Boston, 1907.

Each step in the united scales of value, hue and chroma is prepared by weight, brought to a proper consistency and applied with uniform brush work. If the resultant sheet fails to satisfy the three measuring tests it is discarded. This method is continued until a final sheet succeeds, and from this accurate sheet are cut the squares of color appearing on the charts. Protected from dust and the furtive hand, these scales will suffer only a slow change observable under the best conditions of opaque pigmentation. Visual discrimination being rarely less than two per cent⁶ these changes are negligible for a long interval, after which fresh sheets will be supplied.

A color sphere established by the test of visual balance

Desire to fit a chosen contour, such as the pyramid, cone, cylinder or cube, coupled with a lack of proper tests, has



led to many distorted statements of color relations, and it becomes evident, when physical measurement of pigment values and chromas is studied, that no regular contour will serve. If a regular contour is desired, it will be necessary to bring the unbalanced character of pigments to a balance of complementary qualities, by selecting hues of equal light, strength and area.

For this purpose Rünge's sphere (1810) offers a convenient test, although the test at once reveals errors into which he fell:—partly by unmeasured assumptions as to the strength and light of colors, and also by the false but popular theory on which he worked. Strange to say that theory is still prevalent in primary education, although rejected by science for half a century.

Neutral gray is at the center of the sphere. It represents a balance of pigment mixture as white light represents the

⁶ CHARLES PIERCE. Note on the sensation of color. *Amer. Journal of Science*, XIII, 1877, 249 ff. (Photometric sensibility of the eye the same for all colors.)

union of spectral hues. A circuit of pigment hues around the equator is formed of five complementary pairs,—all of equal chroma to accord with equal departure from neutrality, and of equal value to accord with the central level. The sphere is mounted so as to permit rapid rotation, which melts this equator of ten balanced hues in a band of neutral gray, proving by this visual balance that all degrees of sensation are compensated and constitute a true color equator.

Lighter zones to white and darker zones to black are similarly established, and at high speed the spherical surface fuses into a neutral gray, reproducing the axis with its regular scale of values from white to black. This retinal fusion begins to break up as the speed slackens, until a point is reached where a certain rate of presentation causes this hue-sequence to appear almost prismatic in vividness.⁷

This color sphere is evidently smaller than the complete color solid,—its equator being restricted to the chroma of the weakest pigment, since any enlargement of the diameter would leave that hue space vacant and destroy the balance. (Black pigments reflect nearly 20% of light and to balance this at the pole, a light grey replaces white.) The weakest pigment is a blue-green known as Viridian (sesquioxide of chromium), whose red opposite, Vermilion (sulphuret of mercury) is the strongest, with a chroma double that of Viridian. Hence, the equator of the sphere presents only the “middle” or half chroma of Vermilion with chromas less than the maxima in every case except that of Viridian.

The maximum red chroma therefore projects beyond the sphere and is below the level of the equator, with the purple and blue maxima lower still, while the maximum of yellow occupies a very isolated position nearly on a level with white. When these very uneven maxima projecting beyond the spherical surface are connected by intermediate mixtures and their series to white and black, they describe a most irregular shape which may be termed a *color tree*. The white-black axis becomes the trunk of this tree with branches extending horizontally to the maxima of red, yellow, green, blue and purple:—and upon studying its uneven contour, the “color belt”⁸ is found to be a complex circuit whose steep inclination to the axis is a quantitative and qualitative statement of the strongest pigment mixtures.

⁷ Probably produced by most favorable moment of fatigue of the complementary sensation.

⁸ HOWARD C. WARREN. The Form of the Color Pyramid. *Psychol. Bulletin*, VII, 1910, 51f.

In this color solid the relation of axial length to diameter is an interesting question:—a space relation involving a study of the greatest number of discriminations in the white-black series as compared with a similar series of discriminations in the hue circuit. Also of chroma discriminations possible between complementary maxima. Koenig is quoted as ascribing seven hundred distinguishable grays to the axis with only one hundred and sixty distinguishable hues,—while Aubert⁹ increases the latter series to more than a thousand. For a definite study of this ratio in terms of spectral hue and chroma, the apparatus described by Yerkes and Watson¹⁰ seems admirably adapted.

This being a *pigment system*, led to inquiry among dyers and makers of colored stuffs, where one finds some twenty practicable grays as against more than seventy practicable hues in imitation of the circuit: and since the color belt—whether spectral or pigmentary—contains the differences of the white-black series plus the purples, it seems natural to infer that the belt presents the larger number of steps.

The angular distribution of hues is such that a single plane containing the vertical axis selects complementary pairs as determined by visual balance. When three planes separated by 120° are employed the retinal balance is composed of three sensations, while two planes mutually perpendicular give a balance of four sensations.

Another test consists in taking the opposite of red—blue-green—and separating blue from green by 72° . If this be the proper angle they will unite in a blue-green chroma corresponding to a chord joining them, and any other distribution would unduly crowd or spread the remaining hues of the circuit, destroying what painters call the balance of warm and cool color:—i. e. long and short wave-lengths.

A Color Atlas; charts presenting sections of the irregular color solid

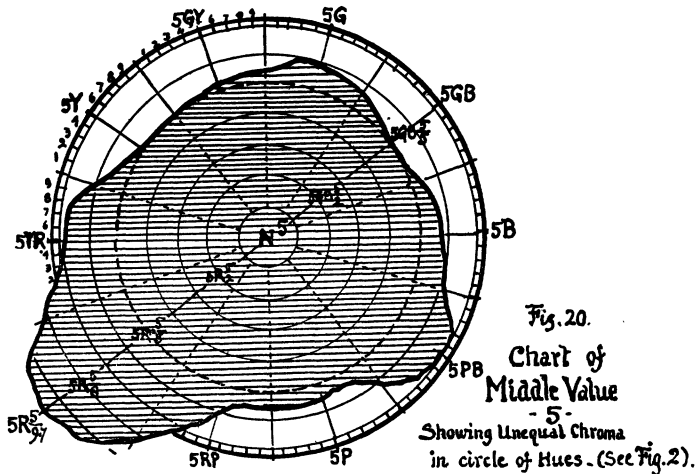
The solid having been built up by equal and decimal steps of sensation, any sections must present regular scales of pigment light and strength. Horizontal sections present colors of uniform value in ten hue-radii of increasing chroma, from the common neutral center to the pigment maxima. Concentric circles contain equal chromas on all radii, and

⁹ H. AUBERT. *Physiologie der Netzhaut*. Breslau, 1865.

¹⁰ YERKES AND WATSON. *Methods of Studying Vision in Animals. Behavior Monographs*, 1, 2, 1911.

an irregular outline describes the shape of the color solid at each level.

Vertical sections through the axis present a hue and its complement, in every step of value and chroma. A circle struck from middle gray shows the limit of the color sphere, the ends of each diameter selecting balanced complements. Oblique sections trace regular sequences which involve change of hue, value and chroma at each step. Such a series including the strongest yellow and strongest purple-blue gives a pigment imitation of the spectrum plus the missing purples.

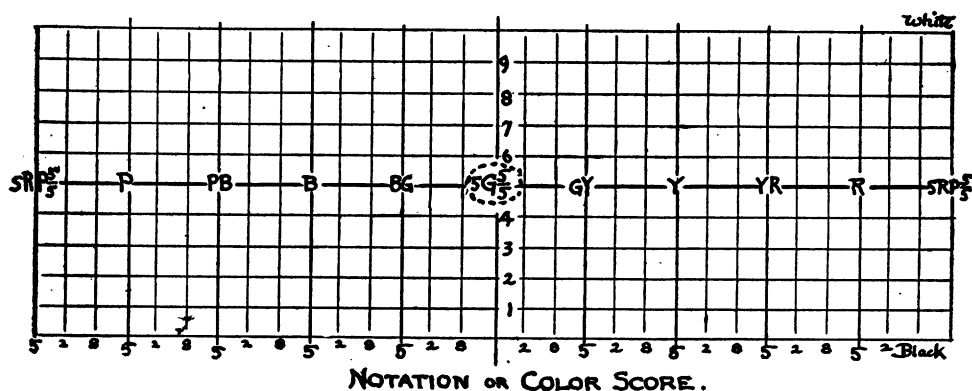


A Color notation¹¹ for records and comparisons

On each chart the steps of color interval are described by a simple notation consisting of an initial and four numerals. This gives their exact place in the related scales of value, hue and chroma. The hue scale is a closed circuit of ten equal steps traced by the initials of the five principals and their intermediates. It is written R (red), Y (yellow), G (green), B (blue), P (purple), and the intermediates YR, GY, BG, PB and RP. Each of these hues is in ten steps of value from black (0) to white (10) and also in ten steps of chroma from neutral gray (0) to the strongest maximum (10). An intersection of these three scales is written by an initial for the hue, a numeral above the line

¹¹ A. H. MUNSELL. *A Color Notation*. Boston, 2nd edition, 1907.

for value and another below the line for chroma. Thus "Middle Red" (midway between extremes of value and chroma) is written 5R $\frac{5}{2}$. When first seen on the equator of the sphere this degree of red is likely to be rejected as untypical; yet it is the type which appears most frequently in beautiful combinations, while the extreme red generally taken as typical is usually absent, or if a small touch is introduced as an accent, it will be found to balance with a correspondingly large area of the weaker blue-green. When fixed in the visual memory, this middle red permits the thought to range by equal degrees to the limits of luminosity



and strength, just as in musical training the middle register is the basis of judgment for the extremes.

Any variation of this middle red is at once defined by the notation. Thus $4R_{\frac{5}{8}}$ is a slight change toward crimson without change of value or chroma. $5R_{\frac{6}{8}}$ indicates no change of hue or chroma, but a lighter value of red, while $5R_{\frac{4}{8}}$ signifies unchanged hue and value, but with a weaker degree of chroma. This method applies to every point in the color solid, and by means of decimals, finer differences are possible up to the limit of visual discrimination.

A Color Score is provided for recording color groups and sequences

Suppose a transparent cylindrical envelope placed around the equator, and cut open at the red-purple meridian. This envelope spread flat is like a Mercator projection permitting us to plot any points of the color solid. It presents a rec-

tangular chart traversed by ten equidistant hue meridians, which are crossed by ten horizontal parallels of value. *Middle green* occupies the center of the chart, where the green meridian intersects the equator. Every point on this chart is equally significant of a certain value and hue, at the side of which may be written the intended chroma. Not only defining the *kind* of color sensation, this chart shows the *quantity* of any color by an enclosing line which is an expression of area. Significant curves traced on this score of measured scales describe individual sensitiveness to color. They serve to plot the groups and sequences which individuals find agreeable or the reverse. They also tabulate any desired or imagined combination of colors, and with practice in notation may be used to fix the memory of natural effects too fleeting for prolonged study.

Finally, by aid of the charts and models, there is set up a fixed mental image of all color relations.

The limits of this paper exclude reference to other practical applications of a definite color method in scientific and artistic education:—but one may feel justified in the hope that by providing what seems to be a sound mathematical basis for the description, comparison and classification of colors, there results an instrument that may be of use to psychologists.